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REVIEW OF METHODOLOGY FOR ECOLOGICAL INVENTORIES FOR PLANNING AND MANAGING SURFACE MINING OPERATIONS AND AFTER MINING REHABILITATION

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REVIEW OF METHODOLOGY FOR ECOLOGICAL INVENTORIES FOR PLANNING AND MANAGING SURFACE MINING OPERATIONS AND AFTER MINING REHABILITATION

A FINAL REPORT SUBMITTED

by

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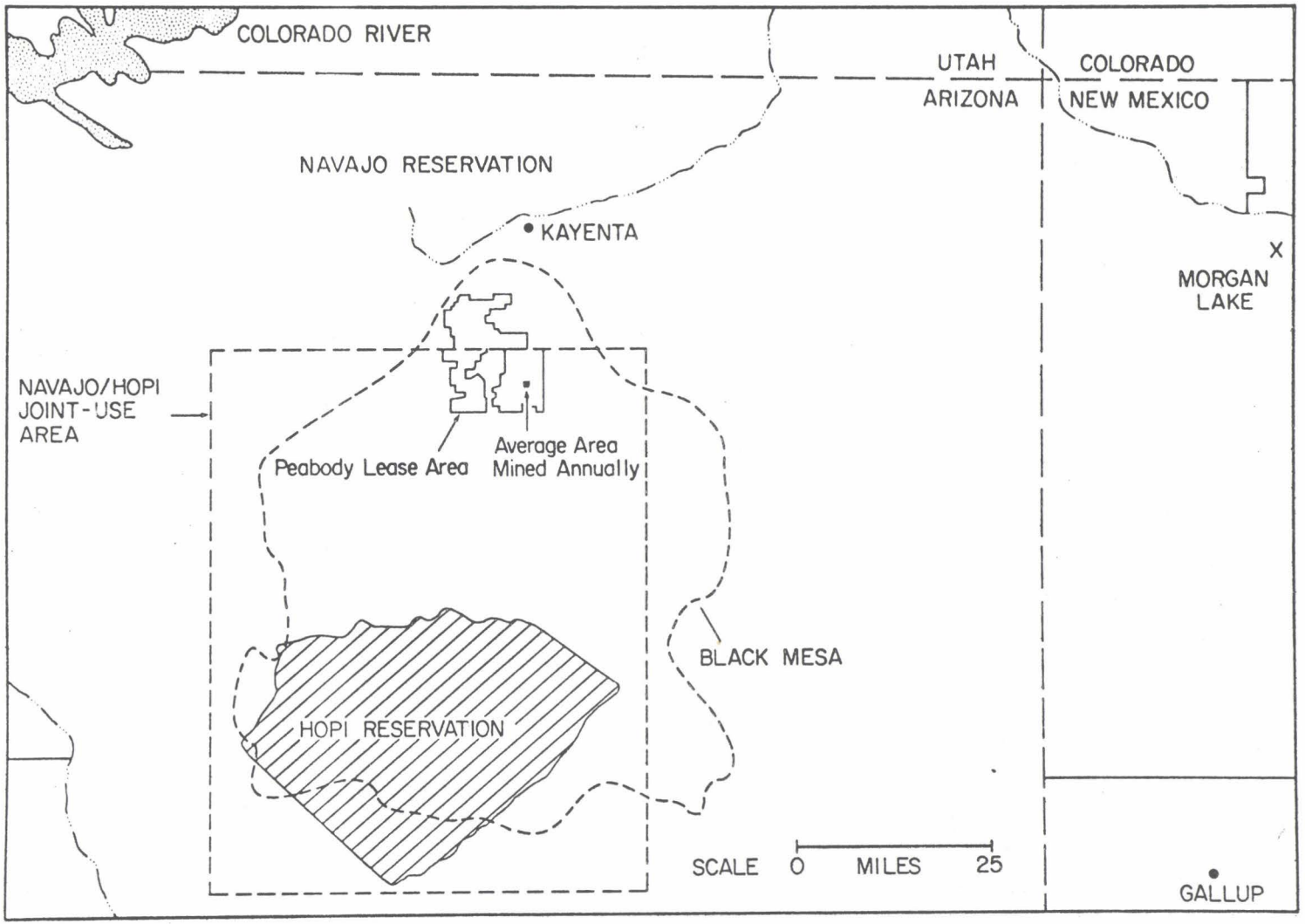
INTRODUCTION

Due to the nation's growing needs for fuel, minerals and ores, it is expected that surface mining in the Rocky Mountain West will expand rapidly during the remainder of the 1970's and beyond. Environmentally sound planning and control of this mining, and follow up reclamation, will require an ecological data base for the areas involved.

Arizona has about 3,060 square miles of coal deposits most of which are in the Black Mesa (Figure 1) area of the Navajo and Hopi nations. The Peabody Coal Company has leased 64,858 of this land and plan to mine 14,000 acres at the rate of 400 acres annually.

The effects of strip mining on ecological values in arid regions are not well known, but are commonly assumed to be detrimental. Even less is known of the effects of reclamation. Reclamation almost always involves the introduction of non indigenous plant species which could have ramifications down ecological chains of the surrounding area. An ecological inventory is basic to determining the environmental impact of mining and subsequent reclamation. No such inventory has been made on the coal deposit areas of the Black Mesa.

The purpose of the project was to prepare an intensive inventory of a selected area of several square miles in which mines will be



THE BLACK MESA REGION IN NORTHERN ARIZONA.

developed within the next two or three years. The data can be used as a basis for:

1) Assessing the environmental status of an area of the Black Mesa before mining
2) Reclamation planning compatible with environmental values
3) Essential input for ecological models being developed through The Analyses of Ecosystems (IBP) for arid lands
4) Evaluating the ecological effects of surface mining operation in the southwest

Although environmental impact statements have not been required for mining operations on the mesa, the information should be valuable in their evaluation for nearby areas where they are required.

The project was to inventory the biota, soils, climate, geology and hydrology of the area to provide data on the state variable of the system. Subsequent study of the change in these state variables due to pertubation by mining and reclamation will supply information needed to elucidate characteristics of the system such as productivity, energy flow and nutrient cycling and how they are affected by the mining operation. The information has been collected in a manner that can be used in the syntheses presently being developed by the Desert Biome portion of the Analysis of Ecosystems Program. The specific objectives of this study were to:

1) Review methodology for establishing a practicable ecological data base for an area to be surface mined.
2) Pilot test the system developed in the Black Mesa area of Arizona.

REVIEW OF METHODOLOGY FOR ECOLOGICAL INVENTORIES

Information obtained through literature review provides the perspective for defining and selecting criteria most appropriate to the current needs of the ecological inventories. There is a general consensus that ecological base line inventories should include a description of the environment, a prediction of potential impacts, distinction between man-induced effects and natural effects and the temporal effects of short-term vs long term responses. Keenlyne (1977) outlines the basic steps for determing the impact of energy development on wildlife. The need for ecological information in the management decision process is emphasized by Johnson (1976). He also indicated that one of the goals of environmental assessment is to match the classes of perturbations with the classes of response which would result in the prediction of ecological effects based on the measurement of key variables and the potential for mitigation of technological impact and enhancement of the ecosystem. The need to separate man-induced effects from natural effects and determine cause and effect mechanisms through the selection of appropriate parameters which sample elements of ecosystem structure and function is emphasized by Dietz (1976).

Studies at the individual or organism level provide insight into mechanisms of change. Investigation at the population level is necessary to estimate the number of organisms that may be removed or exploited without significantly impacting the population. Studies are conducted at the community or ecosystem level to detect variations from natural

dynamics and succession. Often an impact at the ecosystem level will cause a change in the pace of naturally occurring processes; the problem, then, is detecting additional changes above naturally occurring processes--not comparing changes in values of various parameters over time (Sharma, 1976).

Zar (1975) states that the functional relationships of ecosystem components need to be considered in study design in order to be able to predict the effects of altering any of the components. Christensen et al (1975) emphasize that both the definition and assessment of impact should be at the ecosystem level and should involve all the structural and functional parameters important in characterizing the ecosystem.

Sharma (1975) adds that site-specific, as well as region-wide studies, are important in determining significance of environmental impact, the site-specific studies providing a reasonably accurate quantitative measure of the impact and the region-wide studies providing information on the extent of the resource impacted.

The concepts of trophic pyramids, niches, and guilds (a guild is a functional category used for combining species that overlap significantly in their utilization of a particular resource) are proposed by French (1977) as useful in explaining the organization or structure of natural systems. The structural and functional aspects of the ecosystem are divided by Barrett, et al (1976) into rate processes, state variables, and driving variables. It is agreed by Dietz (1976) and Eberhardt (1975) that a clear definition of the objectives is required in order to design a sampling program which is amenable to analysis by statistical techniques. A report from Battelle-Northwest (1974) agrees with the need for analytical rigor

and in addition stresses flexibility in adapting the study to the particular site as well as providing quantitiative evaluation or uniqueness rating of resources where feasible and appropriate. Buffington, et al (1976) suggest that another dimension of assimilative capacity of a system by recognized and accounted for in impact assessment.

There exist a few common broad criteria which are generally agreed on for parameter selection. The ease of measurement, the cost in time and money, and general logistical convenience fall in this category (Hirsh 1976, Johnson 1976, Battelle-Northwest 1974). It is also generally agreed that the sensitivity of the parameter to the perturbation anticipated is important. Odum and Cooley (1976) suggest the "performance curve" as a graphic form for assessment of the gradient of impact which an activity has on the system. Use of such a curve can provide predictive capability.

There exists some disagreement on the value of indicator species for purposes of impact assessment. Some, such as Battelle-Northwest (1974), feel that biological indicators should not be used because they require a high degree of interpretation by an ecologist familiar with the area, the indicators may not be comparable from site to site, and multi-factor impacts are confounded in these indicators and become difficult to interpret in a cause and effect framework. Risser (1975), however, feels that indicator species may be valuable because they are easily understood by the non-scientific public and therefore provide a good vehicle for communication. Plus they provide an index which synthesizes the effect of undefined arrays of environmental conditions and may also indicate important interactions with other species potentially significant in the structure and function

of the community. He does, however, suggest that they should be used only when certain conditions can be met. Buffington (1975) and Wielgolaski (1975) generally agree that indicator species may be useful but only under certain conditions and much basic research needs to be done to really make them effective.

The literature suggests long lists of a wide variety of parameters which may be useful in ecological baseline studies. Alden (1974), Hirsh (1976), Barrett el al (1976), suggest examples of parameters to be measured ranging from aesthetic characteristics of the site to measurements on the structure and function of the ecosystem. The importance of integration in ecological baseline investigations is emphasized by Cooper (1975), who suggests the measurement of such properties as ecosystem respiration, and the ability to detoxify an undesirable substance plus nutrient and water cycling and primary production. Absolute density or biomass density measurements on components, productivity measurements, and a variety of ratios are suggested by Battelle-Northwest (1974) and French (1977).

Following is a discussion of practical criteria for selecting parameters to be measured in terrestrial ecological baseline studies in western areas. Application of these criteria to sort from among all possible measurements a subset specific to the needs of a particular energy development activity requires knowledge of site-specific environmental characteristics. This precludes the identification of a standardized list of parameters that can be used inany baseline study but rather necessitates that the user combine informed judgement with adequate system information to design the most appropriate baseline study. The following is to be viewed as the approach

a field biologist might take to study program design, taking into account (in a practical way) the kinds of selection criteria discussed above and tempering it with what we are actually able to do. Some of the most important criteria for parameter selection may be summarized as follows:

1) The parameter being considered represents an important ecological component or process or it is important as a natural resource or as a threatened or endangered species.
2) The parameter is anticipated to be affected by the energy development activities in question.
3) The parameter is identifiable, observable, and available during baseline and monitoring studies.
4) The parameter is amenable to measurement by methods presently available and is consistent with experimental design guideline and statistical analysis requirements.
5) The parameter (and methods employed to measure it) is cost effective (the level of effort and cost necessary to sample the parameter is commensurate with the decision matrix and projected impacts).

The purpose of this review is to define a practical procedure for selecting parameters that will likely meet the objectives of ecological baseline studies. However, on the whole, ecological processes are not amenable to sampling by available state-of-the-art methods. For example, it is difficult to adequately measure plant mortality or reproduction within the cost and time constraints of an ecological baseline study although particular perturbations may have direct and significant effects on these processes. The goal then is to identify ecological parameters

that integrate or provide an adequate measure of the processes which can be readily measured by existing state-of-the-art methods at a supportable level of effort.

Perturbations associated with energy development activities will ultimately result in a change in one or more of the following attributes of biotic systems:

1) species composition
2) species importance
3) standing crop biomass and/or
4) species distribution

Identification of these attributes provides a conceptual framework for integrating the major ecosystem functions that are anticipated to be affected by energy development activities and for identifying appropriate parameters to measure. The attributes are not, however, mutually exclusive.

Determination of species composition provides important qualitative input into the design of ecological baseline studies by ascertaining the presence of threatened or endangered species, economically important species, species with known sensitivity to certain aspects of energy development (e.g., SO_2 emission) or species important to ecosystem structure and function. Changes in species composition may result from energy development-related perturbations through death of species sensitive to particular effluents, destruction of unique habitats, emigration of mobile animals intolerant of increased human activity, change in natural successional dynamics, introduction of exotic species (e.g., for revegetation purposes), etc.

Species importance provides a category for indicating species (and/or species functions) that achieve a measure of importance not logically

falling into one of the other three categories indicated (e.g., important to ecosystem structure and function, because of a large standing crop biomass). A species may be important because of its rare, threatened or endangered status, its economic status, its food preference, or because it performs an important ecosystem function (e.g., pollenation). For vegetation, a synthetic index exists which incorporates relative density, dominance, and frequency of the various plant species sampled to provide a relative measure of species importance. Important species provide a natural focus for baseline study efforts and changes in particular attributed of these species may provide information relevant to determining specific effects of energy development activities.

Standing crop biomass provides an important measure of the importance of various ecosystem components to overall structure and function of the ecosystem. Changes in standing crop biomass caused by energy development activities will result from either a loss of individuals (i.e., reduced density) or reduction in weight of individuals (perhaps due to chronic insults such as gaseous emission or trace elemnnt accumulation). Species distribution as defined here includes both the frequency or presence of species within defined habitats and (for mobile animals) migration patterns. Changes in species distribution from energy developmnnt activities can result from destruction of unique habitats, loss of species in habitats exposed to particular insults or impacts, or (for mobile animals) the obstruction or interference with movement patterns.

The mechanism of change of each of these major attributes may be manifested at different levels of ecosystem organization. For example, reduced growth of individuals of a particular species of plants in close proximity

to an energy facility may ultimately result in a decreased standing crop biomass in a whole plant community. Likewise, increased mortality of a species sensitive to SO_2 emission could result in the elimination of that species and a subsequent change in community successional dynamics.

For each of the four classes of attributes defined above, parameters that (1) provide efficient and cost-effective measures of the attributes at different levels af ecosystem organization, and (2) can be measured with existing state-of-the-art methodology.

A primary objective of the proposed approach is to measure biotic responses that are expected to result from a particular perturbation. However, cause and effect relationships cannot be inferred entirely on the basis of response detection. This has been a major fault of previous baseline studies. When evaluating the effects of a suspected perturbation on a major system attribute, it is important to consider that the observed change may have come about through a chain of events unrelated to the energy development of concern. This necessitates the holistic approach to baseline studies. Vegetation characteristics in turn are often important limiting factors with regard to animals as they provide their ultimate source of critical habitat/features, such as nest sites; food; and frequently, their only source of water.

One of the most important aspects of designing a terrestrial ecological baseline study is the selection of methods that provide cost-effective information on selected parameters within the constraints of experimental design and statistical considerations. To date most of the project efforts have been devoted to the development of a conceptual approach to the design and implementation of ecological baseline studies and the identification of parameters to be measured that are commensurate with the conceptual framework.

1) assumptions
2) applicability to baseline program objectives
3) appropriateness to experimental design and statistical criteria
4) repeatability (i.e., amount of sampling variability introduced by method)
5) skill of personnel required
6) cost
7) quality control procedures

Therefore, the purpose of this section was to demonstrate how the "method selection" procedure will follow logically from identification of appropriate parameters (rather than to present our determination of the "best" methodology available to sample selected parameters).

A Review of Analytical Methods Used in Vegetation Inventories

Morrison, Martin et al (1977) have discussed at length various shortcomings with ecological baseline studies and their integration into decision making processes. They note the failure of many individuals and groups to strive to convert the process of ecological study from an art to a science. They cite complaints by the Fish and Wildlife Service to the effect that much data gathering overstresses inventory making while neglecting careful conception of quantitative baseline definitions, too often resulting in long inventory lists and generalizations that only touch upon such topics as potential ecological effects and procedures for dealing with them; further, reports frequently fail to attempt to integrate the results of ecological studies with technical aspects of the proposed land activity and/or the results from other baseline study programs. Morrison et al discuss various philosophical reasons for this situation

including controversies concerning the jurisdictions of pure vs applied science. They suggest that there is presently a lack of a sufficient information base concerning the response of free-living populations to natural environmental stressors, let alone those produced by the activities of man. They also cite a need for scientists who deal with environmental subjects to confront decision makers with their ideas and to focus their studies with anticipation of the ecological information needs of those who must make decisions. They cite a list of shortcomings common to environmental studies as listed by Battelle Northwest Laboratories (1974):

1) too wide an initial choice of species or parameters
2) inadequate statistical analyses
3) limit of studies to, at most, one year's work
4) absence of true replication in sampling design
5) inadequate sampling sizes

Morrison et al (1977) suggest that ecological parameters and the methods used for their evaluation must provide a "statistically valid quantitative data base that is appropriate for the needs of the impact assessment, mitigation planning and long term monitoring." They note that qualitative methods can be useful in certain applications such as early phase information gathering for baseline definition and in the definition of geographic and temporal limits of the systems to be covered in the baseline studies. They also emphasize the need for increased care in the selection of parameters to be measured. The trend among ecologists to use a holistic approach that considers the systemic interaction of factors and organisms rather than concentrating upon them as independent entities is described. This approach can be combined with the development

of valid functional models of the system under analysis which may have predictive value. However, much more information is needed for the production of functionally accurate predictive models. It is also emphasized that a holistic approach should be taken in the design of baseline studies to insure that consideration is made of the total ecosystem to be studied and its interaction with the project development involved, and that a "political/ legal and socio-economic decision matrix" be defined. Toward this end, they identify five major categories of criteria for parameter selection:

1) ecologically important components and processes
2) likelihood of measurable response to development activities
3) state-of-the-art limitation and professional judgement
4) experimental design and statistical constraints - power of significance test, sensitivity of test, sampling costs, sample unit and size.
5) special criteria (unique habitats, economic importance, threatened and endangered species, etc.)

Keammerer (1974), in an assessment of the vegetation of Parachute Creek Valley in Colorado analyzed 23 stands of vegetation in the preparation of land use and vegetation maps and a species checklist. Communities were examined through the use of combinations of methods including random pairs and quarter methods for trees, line intercepts and belt transects for shrubs and one meter square quadrats for herbs. An annotated species checklist comprised a major part of the inventory. The identification and location of rare species was also included in the inventory, as were community types unique to unusual environments in the area studied. Keammerer found that the primary factors in control of the distribution, structure and composition

of the plant communities were slope, aspect, exposure and past land use (mostly grazing) of the area.

Keammerer (1974) prepared vegetation maps (on a scale of 1:24,000) using air photos and field checking. Lines were drawn around those areas homogeneous in tone and texture on the aerial photos, and then each area on the photo was field checked for vegetation type. It was found that while no two areas were identical, various combination of dominant species tended to repeat and that species tended to cluster in areas where the local environments were within the tolerance range for a particular species. These repeated groupings were identified as communities. Land use maps were produced in a similar fashion. Keammerer noted that the use of larger or smaller scales would have significantly affected the community definitions derived. The maps were finally used to estimate the extent of each vegetation type through the use of a dot counting planimeter.

Keammerer (1974) selected "typical" stands of each vegetation type to be analyzed using criteria of species homogeneity (to avoid mixed vegetation types) and an area of sufficient size to provide an adequate sample. Forest communities were analyzed on three sampling levels: the tree layer, using the quarter method of Cottam and Curtis (1956) or the random pair method of Cottam and Curtis (1949), both of which provided information on tree density, plant size and frequency of occurrence and have proven to be rapid and valid for measurement of these forest parameters; the shrub layer was analyzed using Canfield's (1941) line intercept method and Lindsey's (1955) belt transect which provided information regarding frequency, density and ground cover area; sampling of the herbaceous layer utilized one square meter quadrats distributed in a stratified random

manner where species occurrence and ground cover were assessed. Various combinations of the above methods were applied to different communities, as was deemed applicable. Data from the above analyses were augmented by a comprehensive annotated species list.

Keammerer (1974) identified two communities which he considered unique by virtue of their sharp contrast with the surrounding vegetation, being composed of species of limited distributions within the study area; in this instance, the areas were located near springs and seeps in canyons. Areas in the study region that might qualify as"natural areas" were also noted and described as were rare and/or endangered plant species.

Baseline vegetational studies were conducted near Colstrip, Montana by Taylor, Leininger and Fuchs (1975) in order to assess pre-treatment conditions prior to the establishment of fossil fuel power plants, and to develop measurement techniques, vegetation maps and data for simulation models for use in prediction of bioenvironmental changes produced by fossil fuel power generation in other areas. Methods of study employed included: a description and characterization of each study area with respect to location, topography, soils and vegetational composition; examination of plant community structure by estimation of canopy cover using the method of Daubenmire (1959); numerical diversity studies for individual species and individuals per species using the Shannon-Weaver function, Simpson's D, redundancy using Shannon's H, probabilities of inter-and intra-specific encounter, probability of interspecific transformation (Δ_3) and Fisher's α; an index of site similarity; development of a phenological profile for each study site; plant collection for taxonomic identification and a local herbarium for consultation by field workers; seed collection for use in

future bird and mammal habit studies; permanent ground plot photos using stereo pairs, color and infrared film; and aerial photography in which it was determined that 70 mm color photographs at a negative scale of 1:3,000 will yield 1:5000 prints with sufficient resolution for mapping of plant communities and conspicuous species.

Thames et al(1972) conducted a desert vegetation inventory study in connection with the International Biological Desert Biome Project at Silverbell, Arizona. The site was selected for the validation of a biomass production model. Major species were inventoried and studied for density and ground cover. Prior to these measurements, an analysis of optimum plot size was conducted for those species which could not be inventoried by aerial photography. Ground cover by major species was estimated by dot grid analysis of infrared aerial film imagery.

A Review of Animal Inventory Methods

Stoecher (1974) conducted an inventory of mammals and birds in the Parachute Creek Valley using a combination of methods including direct observation, live-trapping and analysis of tracks and droppings. Trapping was carried out in a systematic and repeatable manner. Twenty traps were set at each of twenty locations; traps were about fifty feet apart and baited with rolled oats in the evenings and examined in the mornings. Four trapping periods of three consecutive nights were used: in late June, late July; early August and mid-August. Sixty trap-nights were used at each site for each period and an index (Ti) was computed as the number of animals captured divided by the number of trap nights. By this means, mammalian abundance between the separate habitat types and habitat quality were estimated. Fourteen hours were spent each month in the location and

identification of bird species. Notes were taken of general levels of abundance, habitats utilized, species which had established territories, nesting species, etc. Generally, observation periods were from two to four hours in the mornings, although some observations were made at other times.

Fautin (1975) used a method of observation at stations along a traverse route in order to study the vertebrate fauna at the Black Thunder Coal Lease in Wyoming. The method consisted of establishing observation stations at one km intervals along four routes. Each route was traversed between 14 and 17 times in the March through August study period; three to five minute stops were made at each station during which the kinds and numbers of vertebrates seen and heard were recorded.

Thames et al (1973, 1974) conducted small mammal population density biomass and distribution studies on the Silverbell IBP Validation Site by a live trapping and marking system that was designed to provide accurate measurements with as little disturbance of the ecosystem as possible. Traps were set equidistantly in two rows and checked twice during each trap night. Captured animals were marked, weighed and released. The effective sample area was computed for each species, assuming that individuals have circular ranges. Several three night trapping periods were run. Total avian biomass was determined monthly by line transect and direct mapping methods. Nesting studies were also made.

A Review of Inventory Methods for Geomorphology, Soils and Water Resources

Land form units can be mapped from interpretation of available air photography, field surveys and examination of numerous geological sections. The measurements of slope inclinations and channel dimensions, together

with the laboratory analysis of sediments can be undertaken where such information additionally appears valuable. Methods for geomorphological inventories have been described by Dalrymple, Blony, and Conacher (1968); DuMontelle, Jacobs, and Bergstom (1971), and Mabbutt and Stewart (1963).

Standard soil survey procedures (Soil Survey Staff, 1951) can be used in mapping the soils of an area. The landscape is traversed at 1/8 mile intervals or less and the cores are taken by hand and/or power augers. Low intensity soil survey maps are usually available (Soil Conservation Service, 1972). Tentative soil type boundaries are established using air photography. Soil profiles for the major soil types are dug and their major horizons are sampled for laboratory analysis (Verma, 1974).

Water resources inventory of an area is usually done from stream gauging stations, records precipitation data and from ground water logs. There are no standard procedure established which can be used universally.

ECOLGICAL INVENTORY OF THE SELECTED WATERSHEDS ON THE BLACK MESA

Physiography

Black Mesa, one of the more predominate features of the Colorado Plateau, is located in the Navajo Indian Reservation and the Navajo-Hopi Joint Use Area within the Apache and Navajo Counties of Arizona. In the classical sense Black Mesa is not a mesa but a basin. This massive highland covers an area of about 2.1 million acres, which is nearly three times the size of Rhode Island. Arising abruptly some 1700 feet above the surrounding plains the Mesa attains an elevation of 7500 feet along its northern and western escarpments, which gently decend to 500 feet, forming the finger shape Hopi Mesas along its southern edge.

Geologically, the Mesa is composed of the Mesaverde Group which consist of sediment deposits laid down during the Cretaceous age. The surface is dissected by a complex system of ephemeral strems which drain into four major washed. The result is a rolling topography interspersed by broad alluvial valleys.

Climate

Due to limited climatogical records on the Mesa, the climatic description of the area is very general. Personal observation indicates that the climate is not atypical for much of the arid Southwest at this altitude. The precipitation is about 12 inches per year; however, this can vary from half to twice this amount. About 50 percent of the total precipitation falls during the summer months of July, August, and September. The period from January to March receives about 25 percent, with

the remaining 25 percent distributed evenly throughout the remaining six months. The summer storms are convective whereas the winter storms are frontal and usually snowfall events.

Summers range in temperature from warm to hot in spite of the relatively high elevation, with the days being in the high 80's and the evenings near the mid 50's. Winter temperature highs are in the mid 40's with lows near 20 degrees Fahrenheit. High winds that occur throughout the year tend to make the winters at times unbearable.

Flora and Fauna

The vegetation on the Mesa changes from a Ponderosa Pine-Douglas-Fir type along its northern escarpment to a depleted shortgrass type along the wouthern edge. The large size of Black Mesa (approsimately 3,200 square miles) and the diversity of its vegetation necessitate a variety of methods for an inventory of its plant life. Black Mesa lies within the Upper Sonoran Life Zone, characterized by sagebrush (Artemisia tridentata), piñon (Pinus edulis) and juniper (Juniperus osteoperma). The piñon and juniper stands are heaviest near the northeastern rim of the mesa, where a maximum elevation of more than 8,000 feet is attained; growth of these species also occurs on hill tops and in canyons and is sometimes associated with Douglas fir, aspen, ponderosa pine and Gambel oak. Moving away from the northeastern rim, the altitude of the mesa gradually decreases and the stands of piñon and juniper are increasingly diluted by grasslands where over-grazing has greatly enhanced the process of erosion of the terrain. The mesa may be divided into three climatic zones: mixed grassland, which occurs between 5,500 and 6,200 feet in elevation with an average rainfall of 8 - 12 inches; sagebrush grassland

between 6,200 and 7,000 feet where annual precipitation averages 12 - 15 inches; and the piñon-juniper forest, occurring above 6,500 feet with approximately 15 - 17 inches of rainfall per year. Gumerman, Westfall and Weed (1972) note that archaeological evidence suggests that little change has occurred with respect to the occurrance and distribution of flora and fauna on Black Mesa from prehistoric times to the present; this is suggestive of climatological and ecological stability in the area.

The vegetation of the area being mined can also be classified into three types: (1) juniper-piñon, (2) sagebrush, and (3) grassland. The juniper-piñon areas are moderately dense stands and have little if any understory or reproduction. Sagebrush areas have the greatest diversity of vegetation. Grasses as well as piñon (which is presently invading many of these areas) seem to grow well at the base of sagebrush on the more moist sites; fourwing saltbush and wolfberry are also found growing well in this vegetation type. The most common grasses seen on the sagebrush and grassland areas are sand dropseed, indian ricegrass and blue grama. However, snakeweed is the most abundant vegetation on the grassland sites.

Very little work has been done on Black Mesa with regard to vegetational analysis. Studies dealing specifically with the mesa are the environmental impact study by Northern Arizona University (1975) and a brief description of plant life on the mesa by Gumerman, Westfall and Weed (1972) in conjunction with an archaeological investigation. A plant species list, compiled from these two sources is given in Appendix I. More extensive works covering the surrounding Navajo and Hopi reservations and the neighboring Four Corners area include BIA Land Operations (1964)

and Hill et al (1973). Other groups are presently doing plant survey work on the mesa in the mine lease area where a combination of aerial photography and ground surveys are being utilized. Work is being conducted by the U.S. Geological Survey in conjunction with a hydrologic study and monitoring program. Information concerning this Black Mesa Monitoring Study is available through the Tucson office of the USGS. VanAsdall and Milsicek of the Biology Department at the University of Arizona have conducted quadrat analyses on the mesa but their data has not yet been published.

Due to the paucity of vegetational information about Black Mesa, particularly the region outside the coal lease area, it was deemed of interest to briefly review plant survey methods used in similar project and/or vegetational areas in the western United States. This review is presented in an earlier section of this report.

It is recommended that a comprehensive survey of plant life on Black Mesa include the following elements: an annotated species checklist; a program of vegetation mapping integrating information derived from an aerial photo survey and supported by verification with data derived from field studies; a description of major plant communities with particular attention to species density, composition and habitat; preparation of land use maps which identify areas of grazing, agriculture, residential structures and mining. The maps should also indicate the intensity of land utilization. The ensuing report should also contain a list of species, habitats and communities that are of particular interest ot the Navajos and others for economic, recreational, scientific, cultural and/or aesthetic reasons; for example, Gumerman et al (1972) indicate that Lycium pallidum, occurring in open areas, is a good indicator of prehistoric sites due to its sensitivity to disturbed or highly organic soil. It is suggested

that the study be designed in such a way as to chacterize the environmental factors that permit the survival of the existing species and habitats. The specific methods used in obtaining data will vary, depending upon the vegetation species present, their density and the nature of the terrain. The large area of the mesa suggests that a combination of aerial photography and field checking would be the most practical method for the preparation of vegetation distribution and density maps. The resolution obtainable from aerial photos is sufficient for this purpose and in many instances, for recognition of the dominant tree and shrub species. It is anticipated that canyons on the edge of the mesa will have a greater diversity of habitats and species, representative canyons should be examined by ground survey methods and characterized in detail.

Animal life on Black Mesa is exceedingly sparse and Gummerman, Westfall and Weed (1972) suggest that this may have been true in the past since excavated sites on the mesa have been particularly lacking in faunal remains. They note, however, that this may be partly due to the highly corrosive nature of the soil which may have destroyed traces of animal life. They describe the present wild animal life on the mesa as being "largely confined to jackrabbits, cottontails, assorted rodents, lizards, rattlesnakes and small birds". It has been noted that there are no fisheries within the mining project area of Black Mesa (Northern Arizona, 1974).

In September of 1974, a brief small mammal trapping study was conducted on two Black Mesa watersheds, the results of which are included in this section. Appendix II contains an incomplete animal species list, partially derived from this study. A short review of animal inventory methods is also included. A number of the animals listed in the appendix have not been seen in the area for many years.

Two Black Mesa watersheds were trapped for small mammals from September 26-29, 1974. Three sites were trapped on each watershed. At each site two parallel lines of traps were set 15 meters apart. Each line consisted of sixteen stations with two traps at a station for a total of 64 traps. On each watershed two sites were set with snap traps (one rat and one museum special per station) and the third site was set with Sherman live traps. The traps were set at sundown on the first day and checked, rebaited and reset at 2200 and daybreak each of the three days of trapping. The bait used was rolled oats for the live traps and rolled oat-peanut butter mixture for the snap traps. Each site sampled one hectare.

The tree sites on Upper Basin A were set in the following habitats: Sagebrush 1 (SB-1) was a snap trap site in a nearly pure sagebrush stand. Sagebrush-piñon (SBP-1) was a snap trap site in a mixture of sagebrush and piñons of three feet or less. Live 1 (L-1) was a live trap site half in the piñon-juniper stand and half in nearly pure sagebrush. The three sites on Upper Basin B were set in the following habitats: Sagebrush 2 (SB-2) was set as was SB-1. Rock 1(R-1) was a snap trap site in a piñon-juniper stand with one third of the site in a rocky outcrop. Live 2 (L-2) was a live trap site, one fourth of which was in piñon-juniper and the rest in nearly pure sagebrush.

The captures for the three nights and two days of trapping at each site are given in table 1. Populations were very low and no population estimate was possible.

In addition to the trapping sites described above, a few traps were set near rodent burrows on a sandy flat (Flats) between the two watersheds. Location of all trap sites are shown on the attached map.

Although the data is limited (small samples) it is possible to detect ecological preferences for those species caught that are consistent with what is known of their natural history elsewhere.

The following paragraphs are a prediction of the effect of strip mining and land reclamation on small mammals at two watersheds on Black Mesa.

Deer Mouse (Peromyscus maniculatus) - Found in all habitats trapped; populations will probably become re-established after reclamation.

Piñon Mouse (Peromyscus truei) - Restricted to stands of piñon juniper; unless stands of these trees are replanted, it does not seem likely that this mouse will inhabit the area.

Stephen's woodrat (Neotoma stephensi) and Rock Squirrel (Spermophilus variegatus) - Restricted to rocky outcrops: These animals prefer rocky situations throughout their range and will be eliminated from Black Mesa if this habitat is destroyed.

Jack Rabbit (Leticus californicus) - found in all habitats

Colorado Chipmunk (Eutamias quadrivitatus) - Prefers small trees and brush; probably will re-establish along streams and other areas where brush is allowed to grow.

Apache Pocket Mouse (Perognathus apache) and Silky Pocket Mouse (Perognathus flavus) - should become re-established in grassland areas.

Ora's Kangaroo Rat (Dipodomys ordii) - requires sandy soils of moderate depth; generally does not inhabit rocky soils and will probably not become established unless sandy areas remain unaltered.

A summary of the distribution of small mammals by habitat is shown in table 2. All species are supported by voucher specimens deposited in the Mammal Collection at the University of Arizona. These specimens are labeled: 15 mi. SE Kayenta, 6700', Navajo Co., Arizona.

Birds and reptiles were not censused since few birds were seen on the watersheds - most were observed on the flats between the watersheds (Sparrows) and near Al Grant Lake (Dove). No reptiles were observed.

Soils

Most of the soils on the Mesa are classified as Natrargids, poorly developed and badly eroded. Grazing practices have left the ground unprotected and vulnerable to wind and water erosion processes. These processes have lead to shallow soil depths and numerous rock outcrops over much of the Mesa. On the areas that have been mined the overlaying rock material has been broken up, thereby creating a soil material varying from 50 to 100 feet thick.

Hydrology

The Black Mesa hydrologic basin contains three separate multiple aquifer systems. Navajo Sandstone, Coconino Sandstone and DeChelly Sandstone are the principal water bearing units. However, Navajo Sandstone is the aquifer used for the industrial wells that have been drilled on the Mesa since it is the only aquifer in the area that is capable of

yielding more than 100 gallons per minute. The recharge area for that part of the aquifer under Black Mesa is about 20 miles northeast of the Mesa and is about 100 square miles in size. Ground water movement in the recharge area is between 2 to 4 feet per year; the accuracy of this estimate is supported by an age of about 15,500 years for water withdrawn from the aquifer about 40,000 feet down-gradient from the recharge area. The confined aquifer values for hydraulic conductivity of 0.4 to 0.7 foot per day and storage coefficients of 10^{-3} to 10^{-4} are not unusual for fine sandstone, of which Navajo Sandstone is composed (McGavock & Levings, 1973). However, two features give this aquifer its high yields: (1) a high saturated thickness on the order to 700 feet at the wells and (2) a pinchout of the Navajo Sandstone along the eastern escarpment therby keeping the potentiometric surface from decreasing rapidly.

Pumping is currently at the rate of 4700 acre-feet per year from this formation, of this 3700 acre-feet was withdrawn by the 6 industrial wells. It should be remembered that an artesian aquifer, as under Black Mesa, is a pressure over a wide area. Although no drop in water levels has occurred since the industrial wells started pumping in 1970, any future development should be carefully evaluated.

Surface water is the arbiter of life in the arid environment. Hydrologic data on the surface hydrology of the Mesa, until recently was limited to direct observations only. Instrumentation, consisting mostly of crest-stage gages were installed by the U.S. Geological Survey two years ago on some of the larger washes that drain into the Moenkopi. However, with the apparent randomness and restricted nature of the events, many years will be necessary before any significant conclusions can be

made. The general condition of the Mesa indicates low infiltration rates and high runoff rates.

Present Land Use

The dominant land use on the Mesa is grazing. Herding has been an important part of the Navajo's way of life. Thus, on the Mesa very little of the present area to be disturbed is better than a poor range classification. This is due to the almost total lack of forage species on the sites, the lack of litter, and overuse. Overgrazing is one of the chief causes for the present condition of the land. Sheep and goats with some cattle are the general grazing stock. It is estimated that the present level of stocking is twice if not three times greater than what the acceptable stocking rate should be. Range management is the only way of returning the land back to its maximum capabilities. Of the areas to be mined, only the areas classified as sagebrush, approximately 50 percent of the area, has a medium potential for range improvement. The remaining 50 percent has a classification of low potential for range improvement, primarily due to shallow soils.

Coal mining has been active on the Mesa since 1970, presently there are two mined in operation. The coal lies in several seams, which vary in thickness from 5 to 28 feet, and lie within 130 feet of the surface. The coal deposits are strip mined by the furrow technique with dragline equipment. The process leaves the overburden material which is composed of siltstone, mudstone, and sandstone in a series of steep narrow ridges. The reclamation efforts involve recontouring these ridges into a aesthetically pleasing landscape compatible with the surrounding area which is then reseeded with a mixture of native and of native and introduced grasses

and forbs. When the mining is in full production approximately 400 acres per year will be disturbed over the next 30 years.

SUMMARY

The general methodology for ecological inventories was reviewed with special emphasis on vegetation. Other topics considered included animal ecology, geomorphology, soils and water resources. The physiography, climate, flora, fauna, hydrology and land use on the Black Mesa were discussed and previous studies were reviewed. Specific recommendations were made concerning future comprehensive plant life surveys on the Mesa. The results of a brief small mammal study made in the coal lease area were presented and the Appendices include partial plant and animal species lists for Black Mesa.

Table 1. Number of rodents of each species taken at each site. See text for description of sites.

Species	SB-1	SBP-1	L-1	SB-2	R-2	L-2	Flats	
P. maniculatus	3	4	1	-	2	3	1	
P. ruei	-	-	5	-	2	1	-	
N. stephensi	-	-	-	-	1	-	-	
S. variegatus	-	-	-	-	3	-	-	
E. quadrivitatus	-	1	-	-	-	-	-	
P. apache	-	-	1	-	-	-	-	
P. flavus	-	-	-	-	-	1	2	
D. ordii	-	-	-	-	-	-	1	
Totals	(3)	(5)	(7)	(0)	(8)	(5)	(4)	(32)

Table 2. Number of rodents of each species taken by habitat.

Species	Piñon juniper	Sagebrush piñon	Sagebrush	Grassland sage, sandy	Rocky	
P. maniculatus	1	4	6	1	2	
P. truei	7	-	-	-	1	
N. stephensi	-	-	-	-	1	
S. variegatus	-	-	-	-	3	
E. quadrivitatus	-	1	-	-	-	
P. apache	-	-	1	-	-	
P. flavus	-	-	1	2	-	
D. ordii	-	-	-	1	-	
*L. californicus**						
Totals	(8)	(5)	(8)	(4)	(7)	(32)

*L. californicus was found in all habitats.

APPENDIX I

Partial plant species list for Black Mesa compiled from Northern Arizona University (1975) and Gumerman, Westfall and Weed (1972).

Common name	Scientific name
piñon pine	*Pinus edulis*
juniper	*Juniperus osteosperma*
Douglas fir	*Pseudotsuga taxifolia*
aspen	*Populus tremuloides*
ponderosa pine	*Pinus ponderosa*
Gambel oak	*Quercus Gambelii*
Blue stem or Western wheatgrass	*Agropyron smithii*
sand dropseed	*Sporobolus cryptandrus*
Indian rice grass	*Oryzopsis mesia tridentata*
snakeweed	*Gutterezia sarothrae*
wolf or squaw-berry, desert-thorn	*Lycium pallidum*
tamarisk	*Tamarix sp.*
Cholla	*Opuntia whipplei*
prickly pear	*Opuntia sp.*
blue grama	*Bouteloua gracilis*
Squirrel tail	*Sitanion sp.*
Mutton bluegrass	*Poa fendleriana*
Bitterbrush	*Purshia tridentata*
snowberry	*Symphoricarpos sp.*
Fendlerbush	*Fendlera sp.*
cliffrose	*Cowania mexicana*
sagebrush	*Artemisia arbuscula*
yucca	*Yucca sp.*
Russian thistle	*Salsola kali*
cheatgrass	*Bromus tectorum*

APPENDIX II

Partial animal species list for Black Mesa complied from this study and Northern Arizona University (1975).

Common name	Scientific name
piñon mouse	*Peromyscus truei*
deer mouse	*Peromyscus maniculatus*
Stephen's woodrat	*Neotoma stephensi*
rock squirrel	*Spermophilus variegatus*
Colorado chipmunk	*Eutamias quadrivitatus*
Apache pocket mouse	*Perognathus apache*
silky pocket mouse	*Perognathus flavus*
Ord's kangaroo rat	*Dipodomys ordii*
Mule deer	*Odocoileus hemionus*
Black bear	*Euraretos americanus*
Mountain lion	*Felis concolor*
Coyote	*Canis latrans*
Bobcat	*Lynx rufus*
Gray fox	*Urocyon cinereoargenteus*
Wild dogs	*Canis domesticus*
Badger	*Taxidea taxus*
Striped skunk	*Mephitis mephitis*
Spotted skunk	*Spilogale putorius*
Ringtail	*Bassariscus astutus*
Whitetail prairie dog	*Cynomys gunnisoni*
White-tailed antelope squirrel	*Citellus leucurus*
Rock squirrel	*Citellus variegatus*
Valley pocket gopher	*Thomomys bottae*
Black-tailed jackrabbit	*Lepus californicus*
Turkey	*Meleagris gallopavo*
Piñon jay	*Gymnorhinus cyanocephalus*
Mourning dove	*Zenaidura macroura*
Raven	*Corvus corax*
Bald eagle	*Haliaeetus leucocephalus*
Golden eagle	*Aquila chrysaetos*
Red-tailed hawk	*Buteo jamaicensis*
Ferruginous hawk	*Buteo regalis*
Turkey vulture	*Cathartes aura*

BIBLIOGRAPHY

Alden, Howard R. (1974) Environmental impact assessment: a procedure for coordinating and organizing environmental planning. Thorne Ecological Institute, Technical Publication No. 10.

Barrett, G. W., Van Dyne, G. M., and Odum, E. P. (1976) "Stress Ecology" Bioscience 26:192-194.

Batelle-Northwest. (1974) Environmental impact monitoring of nuclear power plants: source book of monitoring methods parts 1 through 8. Battelle-Northwest, Laboratories for Atomic Industrial Forum, Inc. Washington, D.C.

Buffington, J. D. (1976). "A synthetic definition of biological significance." In: Proceedings of nuclear regulatory commission workshop on the biological significance of environmental impacts. Held at the University of Michigan, Ann Arbor. June 4-6, 1975. U.S. Nuclear Regulatory Commission, Washington, D.C.

Canfield, R. H. (1941) "An application of the line interception method in sampling range vegetation." J. Forestry 39:388-394.

Christensen, Sigurd W., Van Winkle, Webster, and Mattice, Jack S. (1976) "Defining and determining the significance of impacts: Concepts and methods." In: Proceedings of the conference on the biological significance of environmental impacts. Rajendra K. Sharma, John D. Buffington and James T. McFadden (eds.) U.S. Nuclear Regulatory Commission, Washington.

Cooper, W. E. (1975) "Ecological effects." In: Proceedings of nuclear regulatory commission workshop on the biological singificance of environmental impacts. Held at the Univ. of Michigan, Ann Arbor. June 4-6, 1975. U.S. Nuclear Regulatory Commission, Washington, D.C.

Cottam, G. and Curtis, J. T. (1949) "A method for making rapid surveys of woodlands by means of pairs of randomly selected trees." Ecology 30:101-104.

Cottam, G. and Curtis, J. T. (1956) "The use of distance measures in phytosociological sampling." Ecology 37:451-460.

Dalrymple, J. B., Blong, A. J. and Conacher, A. J. "An hypothetical nine unit land surfacemmodel." Zeitschrift fur Geomorphologie 12:60-76.

Davbenmire, R. F. "A canopy-coverage method of vegetational analysis" Northwest Science 33:43-64.

Dietz, Donald R. (1976) Proposed monitoring guidelines. U.S. Dept. of the interior, Fish and Wildlife Service Conservation Division, Area Oil Shale Supervisores office Grand Junction, Colorado.

Du Montelle, P. B, Jacobs, A. M. and Bergstrom, R. E. (1971) "Environmental terraine studies in East St. Louis area, Illinois." In: D. R. Coates (Ed.) Environmental Geomorphology.

Eberhardt, L. L. (1976) "Some quantitative issues in ecological impact evaluation." In: Proceedings of nuclear regulatory commission workshop on the biological significance of environmental impacts. Held at the Univ. of Michigan, Ann Arbor. June 4-6, 1975. U.S. Nuclear Regulatory Commission, Washington, D.C.

Fautin, R. W. (1975) "The terrestrial vertebrate fauna of the Atlantic Richfield Company's black thunder coal property in Campbell County, Wyoming" In: Proceedings of Fort Union Coal Field Symposium. Vol. 5 Billings, Montana April 25-26, 1975.

French, N. R. (1977) Ecosystem trophic relationships in habitat classification. Preprint of a paper submitted to proceedings "Classification inventory, and analysis of fish and wildlife habitat." A national symposium, January 24-27, 1977. Phoenix, Arizona.

Gumerman, George J,, Westfall, Deborah, and Weed, Carol S. (1972) Black Mesa: Archiological investigations on Black Mesa, the 1969-1970 seasons. Prescott, Arizona: Prescott college press.

Hill, A. Clyde (1973) Vegetation air pollution investigations in the vicinity of the four corners and San Juan power plants, New Mexico. Air Pollution Laboratory, Dept. of Biology, University of Utah.

Hirsch, Allan (1976) The baseline study as a tool in the environmental impact assessment. Paper presented at the symposium on biological evaluation of environmental impact. 27th annual AIBS meeting, New Orleans, LA.

Johnson, P. L. (ed.) (1976) Role of ecology in environmental management. Report of a workshop, Sept. 9-11. Oak Ridge Associated Universities, Oak Ridge, Tennessee.

Keammerer, W. R. (1974) "Vegetation of parachute creek valley" In: Ecological inventory of the Parachute Creek Valley. Colony development Corp. Denver, Colorado.

Keenlyne, K. D. (1977) Tactical approach for determining impact of energy development on wildlife in Wyoming. Special report Number 1. U.S. Fish and Wildlife Service.

Lindsey, A. A. (1955) "Testing the line-strip method against full tallies in diverse forest types." Ecology 31:567-586.

Mabibutt, J. A. and Stewart, G. A. (1963) "Application of geomorphology in integrated resource surveys in Australia and New Guinea." Revue de Geomorphologie Dynamque 14:7-9.

Morrison, Martin et al (1977) Technical information overview for the "clarification and standardization of the definition. Purpose and practice of ecological baseline studies in western energy development areas." Ecology Consultants, Inc. Fort Collins, Colorado.

Northern Arizona University (1975) Environmental impact studies of the Navajo and Kaiparowits power plants. Fourth Annual Report.

Odum, Eugene P. and Cooley, James L. (1976) Ecosystem profile analysis and performance curves as tools for assessing environmental impact. Institute of Ecology. Univ. of Georgia, Athens.

Risser, P. G. (1975) "Identification and evaluation of significant environmental impacts on terrestrial ecosystems." In: Proceedings of nuclear regulatory commission workshop on the biological significance of environmental impacts. Held at the Univ. of Michigan, Ann Arbor. June 4-6, 1975. U.S. Nuclear Regulatory Commission, Washington, D.C.

Sharma, Rajendra K., Buffington, John D., and McFadden, James T. (eds.) (1976) Proceedings of nuclear regulatory commission workshop on the biological significance of environmental impacts. Held at the Univ. of Michigan, Ann Arbor. June 4-6, 1975. U.S. Nuclear Regulatory Commission, Washington, D.C.

Soil Conservation Service (1972) General soil maps of Garfield County, Colorado. U.S. Dept. of Agriculture, Washington, D.C.

Soil Survey Staff (1951) Soil Survey Manual U.S. Dept. of Agriculture Handbook No. 18. U.S. Govt. Printing Office, Washington, D.C.

Stoecher, R. E. (1974) "Animal ecology: An inventory of the mammals and birds of Parachute Creek Valley." In: Ecological inventory of the Parachute Valley. Colony Development Corporation, Denver, Colorado.

Taylor, J. E., Leininger, W. C., and Fuchs, R. J. (1975) "Baseline vegetational studies near Colstrip" In: Proc. of the fort union coal field symposium (Vol. 5) Natl. Acad, Sciences. Billings Montana April 25-26, 1975.

Thames, J. et al (1972) Tucson Basin Validation Site Report. U.S./I.B.P. Desert Biome Res. Memo. 72-3. Utah State Univ., Logan.

Thames, J. et al (1972) Tucson Basin Validation Site Report, U.S./I.B.P. Desert Biome Res. Memo.73-3 Utah State Univ., Logan.

Thames, J. et al (1972) Tucson Basin Validation Site Report, U.S./I.B.P. Desert Biome Res. Memo.74-3 Utah State Univ., Logan.

Verma, T. (1974) "Soils of Parachute Creek Valley" In: Ecological inventory of the Parachute Creek Valley. Colony Development Corp. Denver, Colorado.

Wielgolaski, F. E. (University of Oslo). (1975) "Biological indicators of pollution." Urban Ecology 1(1): 63-80.

Zar, J. H. (1975) "Statistical significance and biological significance of environmental impacts." In: Proceedings of nuclear regulatory commission workshop on the biological significant of environmental impacts. Held at Univ. of Michigan, Ann Arbor. June 4-6, 1975. U.S. Nuclear Regulatory Commission, Washington, D.C.